COMPUTATIONAL MODELING OF ABDOMINAL AORTIC ANEURYSMS TO PREDICT RUPTURE RISK

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An abdominal aortic aneurysm (AAA) is an abnormal, localized enlargement of the aorta, which is the largest blood vessel in the abdomen. If untreated, an AAA will continue to enlarge in size and eventually rupture, which is generally associated with only a 25% chance of survival. The current indicators of rupture risk, based on AAA diameter, are suboptimal. More precise information regarding rupture risk would allow earlier corrective surgery to prevent rupture in some patients and avoid unnecessary surgery for others. This work takes a biomechanical approach to predict rupture, using fundamental mechanical engineering principles coupled with state-of-the-art imaging and computational modeling techniques.

Abdominal CT scan data are used to reconstruct the three-dimensional geometries of AAAs on a computer. Following CT data segmentation, 3-D reconstructions are created using standard "Marching Cubes" triangulation techniques and the known thickness and pixel spacing of each axial CT cross-section. The meshes obtained from the 3-D reconstruction software are not yet refined enough for use in a finite element model, so a conversion program, created specifically for this application, is currently used to detect elements in the meshes with inappropriately severe angles or other features that would create computational errors. The mesh refinement software thus creates improved 3-D meshes that are ready for input into a commercially available finite element software program (Abaqus) for further analysis. An isotropic, nonlinearly elastic model is used to characterize the mechanical properties of the AAA tissues. This finite element model currently assumes a uniform wall thickness, based on the average wall thickness and material properties measured in a published series of 69 patients. Boundary conditions are set using the blood pressure and displacement constraints on the proximal and distal edges of the model. Upon completion of the finite element analysis, the mathematical solution (stresses over the 3-D surface) is transferred to a commercially available display program (Tecplot), which displays the color-coded stresses in standard 3-D views.

Stress analyses were performed on 38 patients with AAAs that did not rupture ("Observation" patients) and on 22 patients whose AAAs did rupture ("Rupture" patients). The Observation patients were observed for at least one year with no rupture or symptoms occurring (the mean observation period was 30 months). The mean observation period for the Rupture patients prior to rupture was 4.2 months. The mean maximum AAA wall stress for the Observation patients was 37.4 N/cm^2 (standard deviation of 8.8 N/cm^2). The mean maximum AAA wall stress for the Rupture patients was 61.0 N/cm^2 (standard deviation of 17.6 N/cm^2). The difference in the mean wall stress between the two groups is very statistically significant (p-values <0.0001) and shows that wall stress is a strong indicator of rupture risk.